

Effects of uprooting tree on herbaceous species diversity, woody species regeneration status and soil physical characteristics in a temperate mixed forest of Iran

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Abstract: We conducted a study to examine the pattern of development of herbaceous plant species, woody species regeneration and soil physical characteristics after tree uprooting in 20-ha areas of Experimental Forest Station of Tarbiat Modares University located in a temperate forest of Mazandaran province in the north of Iran. Soil bulk density, soil texture and moisture from pit and mound (PM) were measured in the laboratory. Results show that the soil bulk density was most in soil deeper layers at mound top, and the soil moisture content was most in soil deeper layers at Pit bottom. Our study supports that the micro-topography of PM (pit and mound) topography will create a mosaic of environmental conditions. This environmental heterogeneity could be responsible for the diversity of herbaceous plant species and regeneration of woody species. It is recommend that the fallen trees with PM structure should remain in the protected area without clearing as the best option for forest restoration. This information can be useful for forest management that attempts to emulate natural processes.

Keywords: disturbance; beech; hornbeam; soil texture; Iran

Introduction

Catastrophic windthrow is a dominant agent for natural disturbance in temperate forests (Palmer et al. 2000), leading to diver-

sity changes of the understory vegetation (Janasova et al. 2010, Kooch et al. 2010). However, effect of soil on windthrow was less known (Arevalo et al. 2000). Windthrow has been reported to increase the diversity of understory vegetation in two Minnesota forests in US (Palmer et al. 2000). Windthrow gaps caused by the uprooting trees lead to distinct soil disturbances. Influence factor of uprooting tree is pit and mound (PM) microtopography, which is interested in scientists for at least 70 years (Lenart et al. 2010) because of its potential influence on soil formation, nutrient cycling, soil morphology, sediment movement, drainage patterns and forest ecology. PM microtopography can influence plant species distributions. Some species prefer pits for establishment (Walker 2000), while the other species prefer mounds (Lenart et al. 2010). A PM complex is generally created with a depression at the former root position (pit) and an adjacent mound (Oheimb et al. 2007).

After a windthrow, temporarily plant species composition is changed in broadleaved species, and plant biodiversity increases. Natural disturbances were found to positively affect biodiversity of plants (Kreyer et al. 2006; Rixen et al. 2007). The uprooting trees have important influences on forest ecology (Ulanova 2000; Peterson 2007). Beech (*Fagus orientalis* Lipsky) is one of the most important forest species in the temperate broad - leaf forest biome and represents an outstanding example of the development of terrestrial ecosystems (Marvie 2007; Kooch et al. 2010). In the north of Iran, pure and mixed oriental beech forests cover 17.6% of the surface land area and represent 30% of the standing biomass. Beech is the most valuable wood - species in the Caspian forests (Marvie 2007). The beech trees are found from 110 m up to 2650 m. a.s.l. At low altitudes, they were mixed with hornbeam (*Carpinus betulus* L.), (Kooch et al. 2010).

Beech trees with large crowns and full foliage, flat rooting system, and higher height of trees are more vulnerable to wind throw in compare to the other species. Thus more number of this species was uprooted via windthrow (Kooch et al. 2008). There is still a lack of information about the role of such PM micro landforms in mixed forests of northern Iran. The objective of this study was to examine the effects of uprooting tree on the devel-

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opment of herbaceous plant species, woody species regeneration and soil physical characteristics. Specifically, we addressed the following questions: (1) how does diversity of herbaceous plant species differ between disturbed and undisturbed patches of the forest floor? (2) Are there differences in density of woody species regeneration from different microsites? (3) How is the variability of soil physical indicators within PMs?

Materials and methods

Site characteristics

This study was conducted in Tarbiat Modares University Experimental Forest Station located in a temperate forest of Mazandaran Province in the north of Iran (N 36°31'56"–36°32'11"; E 51°47'49"–51°47'56"). The maximum elevation is 1700 m and the minimum is 100 m. Minimum temperature in December (6.6°C) and highest temperatures in June (25°C) were recorded respectively. Mean annual precipitation of the study area is from 280.4 mm to 37.4 mm at the Noushahr city metrological station, which is 10 km far from the study area. In this research, dominant stands (relatively undisturbed) were *Fagus orientalis* and *Carpinus betulus*. Bedrock has limestone - dolomite with silty - clay - loam soil texture. Presence of bare roots of trees indicated that soil texture is heavy to restrict plants rooting. The current study is based on several windthrow events from 2005 to 2006 in the experimental forest station (Kooch et al. 2010).

Data collection and analysis

In the summer of 2009, 34 uprooted trees were selected in 20-ha areas of Tarbiat Modares University Experimental Forest Station. Slope and aspect were recorded for each PM (pit and mound). The parameters were measured, such as tree-fall direction, diameter at breast height (DBH, cm), tree length, pit length (m), pit width (m), pit depth (m), mound height (m), mound width (m) and mound thickness (m) in PM location. Circles plots with 4-m radius in intersection of PMs were designed for recording percentage of herbaceous plant cover and woody regeneration status. Two to three witness trees of same species were selected in a distances of 20–30 m from PM. Percentage of herbaceous plant cover and woody regeneration status were recorded at witness tree locations (under closed canopy position). Five microsites were distinguished including mound top, mound wall, pit wall, pit bottom and closed canopy position for soil sampling. Soil samples were taken at soil depths of 0–15, 15–30 and 30–45 cm from all microsites using core soil sampler with cross section of 81 cm² (Kooch et al. 2010). Large live plant material (root and shoots) and pebbles in each sample were separated by hand and discarded. The air - dried soil samples were sieved (aggregates were crushed to pass through a 2-mm sieve) to remove roots for laboratory analysis. Soil bulk density was measured by Plaster (1985) method (clod method). Soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos 1962). Soil moisture content was measured by drying soil samples at 105°C for 24 h

(Ghazanshahi 1997) at the laboratory.

Diversity measures

There are various ways of measuring diversity of plants. In current research, the formulas of Shannon - Wiener (diversity), Margalef (richness) and Hill (evenness) indices were used as follows (Mesdaghi 2001, 2004):

$$H' = - \sum_{i=1}^S (P_i \ln P_i) \quad (1)$$

where, H is Shannon - Wiener index; S is total number of species and P_i is the frequency of the i th species.

$$R = \frac{S - 1}{L_n N} \quad (2)$$

where, R is Margalef richness index; S is number of species; L_n is natural logarithm; N is number of populations.

$$E = \frac{N_2}{N_1} \quad (3)$$

where, E is Hill index; N_1 is $\log \text{base}^{H1}$; N_2 is $1 / (1 - \text{Simpson diversity index})$.

Statistical analyses

We analyzed relationship between PM dimensions and fallen trees volume using Pearson correlation. PAST software package was used to calculate species diversity indices. Independent samples from t -test were performed for comparison of species diversity index and woody regeneration status in PM and under closed canopy position. Differences between soil depths and PM microsites were tested with two-way analysis (ANOVA) using GLM procedure. Relationship between microsites and soil depth was analyzed also. Duncan test was used to separate the averages of the dependent variables, which were significantly affected by differences treatments. The treatment averages for different parameters were tested at $p \leq 0.05$. The software of SPSS v. 11.5 was used for all statistical analysis. Kolmogorov-Smirnov test and Levene test were used to examine the equality of variances at first.

Results

PM characteristics

Five tree species were identified in study area with PM structure. Beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), maple (*Acer cappadocicum* Gled.), lime tree (*Tilia platyphyllus* Scop.) and ironwood (*Parrotia persica* C. A. Meyer) devoted 18, 11, 2, 2, 1 pairs PM, respectively. Mean diameter at

breast height (DBH) was more in *Fagus orientalis*, compared with *Carpinus betulus* species (Table 1). Regression analysis of logged volume (m^3) and PM sizes showed that four characteristics were imposed by log volume. Pit width ($r = 0.419$; $p = 0.014$), pit depth ($r = 0.512$; $p = 0.002$), mound height ($r = 0.488$; $p = 0.003$) and mound width ($r = 0.582$; $p = 0.000$) had significant correlation with volume of logs. Pit length ($r = 0.085$; $p = 0.631$) and mound thickness ($r = 0.085$; $p = 0.633$) showed no significant correlation with log volume.

Table 1. Species of uprooted tree in PM structure in study area

No.	Species	Total trees	Mean DBH (cm)	Mean altitude (m)
1	<i>Fagus orientalis</i> Lipsky	18	59.50 (41–78)	648 (602–694)
2	<i>Carpinus betulus</i> L.	11	44 (37–51)	596 (580–612)
3	<i>Acer cappadocicum</i> Gled.	2	37 (33–41)	580 (550–610)
4	<i>Tilia platyphyllos</i> Scop	2	38 (37–39)	569.5(553–586)
5	<i>Parrotia persica</i> C. A. Meyer	1	37	546

Herbaceous species diversity and regeneration abundance

All herbaceous species were identified and percentage of herba-

ceous plant cover was recorded in different sites, separately (Table 2). It was found that there were 14 herbaceous species in PM position and 16 herbaceous species under closed canopy. *Rubus caesius* (47.38), *Carex acutiformis* (24.52), *Phyllitis scolopendrium* (23.85), *Pteris dentata* (21.38), *Pteridium aquilinum* (21.14), *Pteris cretica* (18.97), *Urtica dioica* (18.35), *Sambucus ebulus* (10.02) and *Viola odorata* (4.55) had the most values of rate of coverage in PM position, respectively. But, species, such as *Asperula odorata* (17.35), *Epimedium pinnatum* (15.94), *Primula heterocliroma* (15.82), *Cyclamen coum* (14.14), *Festuca drymeia* (13.91), *Euphorbia amygdaloides* (12.58) and *Oplismenus undulatifolius* (7.17), were under closed canopy (Table 2). Shannon - Wiener diversity and Hill evenness indices were the most in PM position. Margalef richness showed that there is no significant statistical difference in PM and under closed canopy position (Table 3). Due to investigation of regeneration abundance in different sites, whole of saplings were identified and recorded at DBH (breast height diameter). Result show that studied position had significant difference (at confidence limit of 95%) with considering regeneration abundance. The maximum and minimum of regeneration abundance were found in PM and under closed canopy microsites, respectively (Table 3, 4).

Table 2. Mean rate of plant coverage in PM and under closed canopy

No.	Species	Life form	Cerotype	Family	On PM (%)	Under closed canopy (%)
1	<i>Phyllitis scolopendrium</i> L.	Cryptophyte	Hyrcanian	<i>Aspleniaceae</i>	23.85	0.58
2	<i>Sambucus ebulus</i> L.	Hemicriptophyte	Poly zonal	<i>Caprifoliaceae</i>	10.02	0.85
3	<i>Carex acutiformis</i> L.	Cryptophyte	Hyrcanian, Mediterranean	<i>Cyperaceae</i>	24.52	0.73
4	<i>Oplismenus Undulatifolius</i> (Ard.)	Cryptophyte	Hyrcanian, Mediterranean Poly zonal , Irano –Touranian	<i>Gramineae</i>	1.85	7.17
5	<i>Festuca drymeia</i> M. & K.	Cryptophyte	Hyrcanian	<i>Gramineae</i>	3.08	13.91
6	<i>Euphorbia amygdaloides</i> L.	Hemicriptophyte	Hyrcanian	<i>Gramineae</i>	0.61	12.58
7	<i>Pteridium aquilinum</i> L.	Cryptophyte	Hyrcanian, Mediterranean	<i>Hypolepidaceae</i>	21.14	1.41
8	<i>Epimedium pinnatum</i> Fisch.	Hemicriptophyte	Hyrcanian	<i>Podophyllaceae</i>	0.17	15.94
9	<i>Cyclamen coum</i> Miller.	Cryptophyte	Hyrcanian, Mediterranean, Irano –Touranian	<i>Primulaceae</i>	0	14.14
10	<i>Primula heterocliroma</i> S.	Hemicriptophyte	Hyrcanian	<i>Primulaceae</i>	0	15.82
11	<i>Pteris cretica</i> L.	Cryptophyte	Poly zonal	<i>Pteridiaceae</i>	18.97	0.41
12	<i>Pteris dentata</i> F.	Cryptophyte	Hyrcanian	<i>Pteridiaceae</i>	21.38	0.50
13	<i>Rubus caesius</i> L.	Phanerophyte	Hyrcanian	<i>Rosaceae</i>	47.38	0.47
14	<i>Asperula odorata</i> L.	Hemicriptophyte	Hyrcanian, Mediterranean	<i>Rubiaceae</i>	0.20	17.35
15	<i>Urtica dioica</i> L.	Cryptophyte	Poly zonal	<i>Urticaceae</i>	18.35	0.35
16	<i>Viola odorata</i> L.	Hemicriptophyte	Hyrcanian, Mediterranean	<i>Violaceae</i>	4.55	2.38

Table 3. Statistical characters of plant diversity indices and regeneration abundance

Diversity parameters/ Statistical characters	Mean \pm Standard error		T- value
	On PM	Under closed canopy	
Shannon - Wiener diversity	2.11 \pm 0.01	1.77 \pm 0.07	4.28**
Hill evenness	1.86 \pm 0.04	1.75 \pm 0.09	1.01 ns
Margalef richness	0.76 \pm 0.01	0.70 \pm 0.01	3.14**
Regeneration abundance	18.55 \pm 1.15	10.44 \pm 0.74	5.92**

Notes: ** Significant at the 0.01 probability level; ns is no significant.

Soil characters

Soil bulk density was significantly greater ($p < 0.01$) in mound top ($1.12 \text{ g}\cdot\text{cm}^{-3}$), compared with the other microsites. Soil bulk density was least ($p < 0.05$) at soil depth of 0–15 cm ($1.04 \text{ g}\cdot\text{cm}^{-3}$), compared with at depths of 15–30 cm ($1.06 \text{ g}\cdot\text{cm}^{-3}$) and 30–45 cm ($1.06 \text{ g}\cdot\text{cm}^{-3}$) (Fig. 1). Sand content was significantly most ($p < 0.01$) in mound top (44.16%), compared with pit and under closed canopy microsites. Sand amount was most ($p < 0.01$) in soil depth of 0–15 cm (35.36%), compared with soil depths in 15–30 cm (28.98%) and 30–45 cm (25.54%) (Fig. 2).

Silt and clay amounts were largest ($p < 0.01$) under closed canopy (50.40% and 36.61%, respectively), compared with pits and mounds components. Silt and clay amounts were most ($p < 0.01$) at soil depths of 30–45 cm (44.08% and 30.37 %, respectively), compared with soil depth of 15–30 and 0–15 cm (Fig. 3 and 4).

Soil moisture was significantly higher ($p < 0.01$) in pit microsites, compared with closed canopy and mounds microsites, which is significantly increased ($p < 0.01$) in deeper soil layers (Fig. 5). Relationship between microsites and soil depth had a significant correlation (at the 0.01 probability level).

Table 4. Regeneration abundance of woody species in PM and under closed canopy position

No.	Species	Mean of mound characteristics			Mean of pit characteristics			Regeneration abundance on PM	Regeneration abundance under closed canopy
		Width (m)	Thickness (m)	Height (m)	Depth (m)	Width (m)	Length (m)		
1	<i>Fagus orientalis</i> Lipsky	3.46	1.13	1.30	0.71	3.20	1.38	18.83	10.88
2	<i>Carpinus betulus</i> L.	3.41	1.23	1.36	0.73	3.33	1.48	19.81	10.27
3	<i>Acer cappadocicum</i> Gled.	3.06	1.18	1.25	0.61	2.83	1.56	17	7.50
4	<i>Tilia platyphyllos</i> Scop	3	1.17	1.26	0.61	2.88	1.51	17	8.50
5	<i>Parrotia persica</i> C. A. Meyer	2.87	1.21	1.20	0.61	2.86	1.39	6	9
Total		-	-	-	-	-	-	78.64	46.15

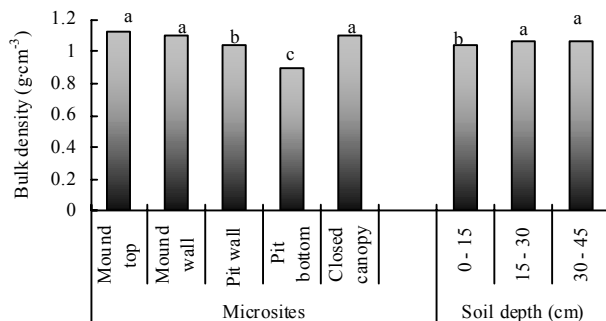


Fig. 1 Mean soil bulk density in different microsites and soil depths

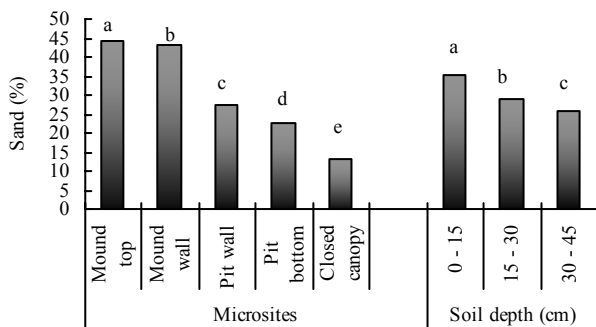


Fig. 2 Mean sand amount in different microsites and soil depth

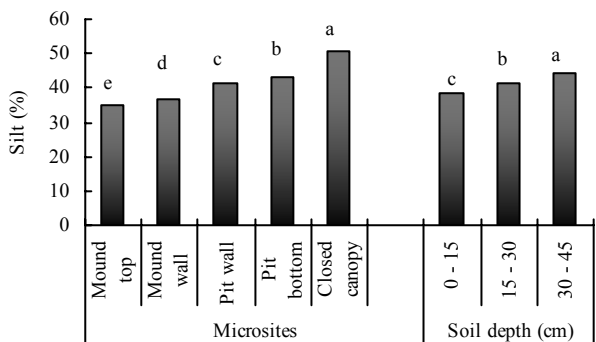


Fig. 3 Mean silt amount in different microsites and soil depths

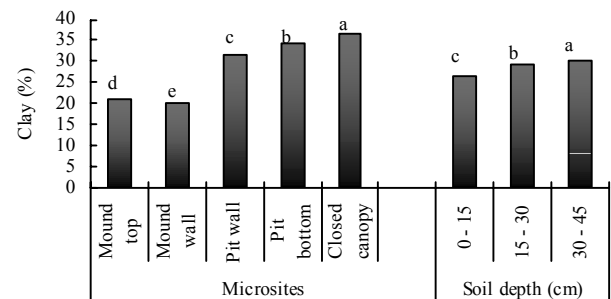


Fig. 4 Mean clay amount in different microsites and soil depths

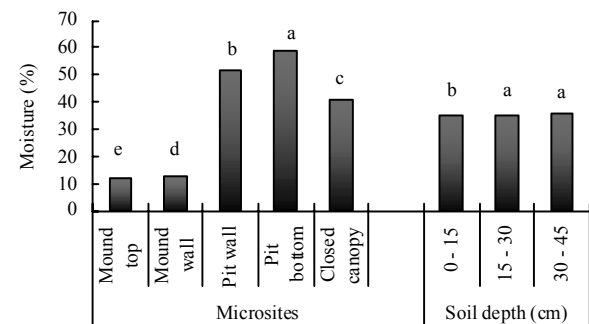


Fig. 5 Mean soil moisture content in different microsites and soil depths

Discussion and conclusions

PM characteristics

Beech has characteristics of full foliage, superficial rooting system, higher height of trees and large canopy covers, thus it is more vulnerable and more damaged from windthrow. In study area, dominant slope aspect is in northeast aspect (between 60%–70%, mostly), thus most trees fell in northeast aspect. Log volume, pit length and mound thickness hadn't significant

relation with log volume using performed regression analysis. In current research, tree trunk was pushed back into the pit, producing a “ball and socket” type (Clinton et al. 2000). This pattern of tree fall helps explain that there is no relationship between the pit length and log volume (Kooch et al. 2008). Mound thickness was not proportional to tree volume, because majority of trees (beech species) were shallow - rooted. Thus, mound thickness was more depended to edaphically conditions than tree dimensions (Clinton et al. 2000).

Herbaceous diversity and woody species regeneration status

Quantitative values of herbaceous diversity indices showed that there is more herbaceous diversity in PM in comparison with under closed canopy. Special conditions in pit (high soil moisture and low organic matter content in soils) and mound high soil temperature and higher amounts of mineral matters microsites) are due to establishments of more plant species in these sites. Many researchers claimed that tree uprooting in PM typically leads to an increase of diversity of the understory (Palmer et al. 2000; Lenart et al. 2010). Current research showed that percentage of *Rubus caesius* species was increased in PM after windfall. The high soil moisture (%) and low temperature in pit bottom microsite (Kooch et al. 2008) created appropriate conditions for *Phyllitis scolopendrium*, *Pteris dentate*, *Pteridium aquilinum*, *Pteris cretica* and *Carex acutiformis* species. Ferns were identified as species characteristic of PMs in different forest ecosystems (Palmer et al. 2000). *Rubus* spp. is an opportunist species that increases in abundance after canopy opening and decreases with canopy closure. Also, this species is specialist in disturbed regions (Palmer et al. 2000). The high frequency of *Rubus caesius* implies that PM is an effective disturbance factor in study area. Peterson and Carson (1996) suggested that dominance by *Rubus* after disturbance is a function of the presence of propagules.

In contrast, this study suggests that the high frequency of *Rubus caesius* is due to existing plants (Palmer et al. 2000; Kooch et al. 2008). It is imagined that the current dominance of *Rubus caesius* will gradually decrease after full canopy closure in the beech forest, but it is difficult to speculate what other compositional changes will occur. In total, PM micro - landform from tree uprooting will create a mosaic of environmental conditions (Oheimb et al. 2007; Phillips et al. 2008; Lenart et al. 2010; Jonasova, et al. 2010), which could be responsible for the herbaceous species diversity. Tree uprooting therefore enhances habitat heterogeneity and provides important microsites for plant establishment (Oheimb et al. 2007). Mound microsite prepared proper bed in increasing sprouting rate of tree species in special conditions including appropriate mineral matter, low organic matter and adequate soil temperature. Ulanova (2000) investigated the effects of windthrow on forests at different spatial scales. He mentioned that regeneration rate of spruce was on mounds more than on disturbed surfaces. Mounds created overland areas in compare with bottomland (Londo 2001). The appropriate volume and temperature of soil are due to increasing of sapling rooting depth (Londo 2001). On the other hand, soil ap-

propriate temperature mentioned was one of effective factors on species sprouting (Kooch et al. 2008). The high moisture and low temperature of soil in pit microsite created appropriate conditions for regeneration of beech species. Thus regeneration abundance of beech in pit microsite was more than that in other microsites in pit site. The results of this research showed that PM sites play an important effective role on regeneration of forest (Elliott et al. 2001; Papaik 2006) in study area.

Soil characters

The soil bulk density was significantly higher in top mounds than in deeper soil layers. Soils are more compressed in deeper layers due to increasing of bulk densities (Jafari Haghighi 2003). By this interpretation, bulk density has a descending trend from upper to deeper layers of soils, which is also visible in our results. Moreover, in upper layers of soil, a soil bulk density is less because of plant roots presence and more activity of organisms. Kooch (2007) found that soil bulk density has a negative correlation with clay content and positive correlation with sand content. Thus the soil bulk density tended to be less in clay soils, compared with sandy soils. A greater amount of clay in pit position is due to decreasing of soil bulk density whereas mound had higher soil bulk density by reason of sand contents gathering. In mounds, clay content hadn't adequate time to transpire in this position. The content of clay was increased in pit. Totally, clay gathering is more occurred in cavity position (Tavakkoli et al. 2008). Clay assemblage in deeper layers of soil is due to transmission phenomenon. Clays and silts are able to transferring to lower horizons. Pit microsite with cavity structure created good position for water gathering thus soil moisture content was increased in this landscape. Less soil moisture content was found in mound microsite due to soil drainage in hill structure (Oheimb et al. 2007). The soil moisture content had most value within pit and least in mound microsite (Barton, et al. 2000). Results of current research showed that PM features created basic changes in soil characteristics (Peterson 2000).

Small -scale windthrow gaps with soil perturbation provide opportunity for the increase in local species diversity in old -growth forests of Iran. Our study supports the view that groups of species differ in response to soil disturbance at PM micro - landforms created by windthrow events. For these reasons, we recommend leaving the fallen trees with PM structure in the protected area without clearing as the best option for forest restoration. This information can be useful for forest management that attempts to emulate natural processes.

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